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# THE SHIFTING OF CLIMATIC ZONES AS ILLUSTRATED IN MEXICO

### BY ELLSWORTH HUNTINGTON[*]

Most of the studies hitherto made upon changes of climate during historic times have been concerned with regions lying between 25 and 45 degrees from the equator, and chiefly in the northern hemisphere. A few investigators, such as Nachtigal in the southern Sudan, have found apparent evidence of changes along the northern borders of the zone of sub-tropical rains; while others, such as Bowman in southern Peru, have found similar evidence south of the equator. The relation of these changes, however, to those which appear to have taken place farther north has not yet been investigated, as is natural in view of the doubt which many students still feel as to the reality of recent changes of climate in any part of the world. The last two years, however, seem to have placed the pulsatory theory of climatic changes upon a firmer basis than hitherto, and to have prepared the way for a study of the subject in areas beyond the arid zone in which practically all the work has thus far been done. The author's investigations on behalf of the Carnegie Institution of Washington in the southwestern United States and in Mexico, as described in recent numbers of this *Bulletin*,[†] the *Geographical Journal*,[‡] the *American Journal of Science*,[§] and *Harper's Magazine*,[‖] have convinced him that these regions have been subject to pulsations of the same nature and magnitude as those of central and western

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[*] A chapter from a forthcoming volume to be published by the Carnegie Institution of Washington under the title "The Climatic Factor as Illustrated in Arid America." Presented in substance at the Ninth Annual Meeting of the Association of American Geographers at New Haven, Dec. 27 and 28, 1912.

[†] Vol. 44, 1912, pp. 801-822.

[‡] Vol. 40, 1912, pp. 264–280 and 392–411.

[§] [Will appear shortly.

[‖] Vol. 123, 1911, pp. 50–58; Vol. 124, 1912, pp. 291–301; Vol. 125, 1912, pp. 292–302.

Asia and the lands surrounding the Mediterranean Sea. This conclusion has been strengthened by an entirely independent investigation of a considerable number of curves of tree growth derived partly from thousands of "stem analyses" made by the Forest Service of the United States and most kindly placed at his disposal by the Forester, Mr. Henry S. Graves, and partly from measurements of the rate of growth of the huge sequoias of California, made by the author. These curves, as is shown in the articles already referred to, are in their main features similar to the curve of climatic change in the eastern hemisphere as derived from observations upon ruins, ancient roads, salt lakes, dry springs, and other phenomena. The logical inference seems to be that the continental regions lying in the more or less arid portions of the globe between 25 and 45 degrees north of the equator in both hemispheres are subject to synchronous climatic cycles, having a periodicity of hundreds and perhaps thousands of years.

If we accept this conclusion, the next problem is the investigation of the possible extension of these changes toward the north and south. One of the best places for such an investigation is Mexico. During the spring of 1912, in pursuance of his work as Research Associate of the Carnegie Institution of Washington, the writer made a journey to the City of Mexico, in lat. 19½° N., to Oaxaca and Mitla, in lat. 16° N., and to the Peninsula of Yucatan, in lat. 20° to 21° N. In all of these places evidence of changes of climate appeared to an unexpected degree. Most of the evidence is similar to that found in the dry regions farther north and in Asia, but there is one interesting and suggestive difference connected with the location of ruins among tropical forests. Taken as a whole the evidence as to changes of climate within the tropics may be discussed under four chief heads: first, the recent fluctuations of the lakes near the City of Mexico; second, the evidences of a change in the conditions of the Basin of Mexico during the time of ancient civilizations; third, the alluvial terraces found near Mexico and in Oaxaca; and fourth, the ruins of Yucatan.

In the *Monthly Weather Review* for November, 1908, I have discussed the City of Mexico and Lake Tezcuco, in their relation to changes of climate. In considering this matter here, I shall largely follow that article, but shall add new facts which have come to light since it was written. The City of Mexico lies 7,400 feet above the sea near the salt lake of Tezcuco, and the tributary fresh lakes of Xochimilco and others. The basin containing these lakes is similar in its general features to that of the Great Salt Lake in Utah, Lop Nor in Central Asia, and Seistan in Eastern Persia. Accurate historic records of the country extend back to the time of the Spanish invasion in 1519, and before that we have fairly reliable traditions for at least 200 years more. It is probable that when Mr. A. F. Bandelier has finished the investigation of manuscripts which he is now conducting on behalf of the Carnegie Institution our information will extend farther back and will be much more full than at present. Taking merely the 600 years for which we now have data we find that during that time there appears to have been a slight but appreciable change of climate in Mexico similar to that which has apparently occurred in Asia. The evidence is somewhat masked because the natural course of events has been interrupted by various works of man, such as the dikes, canals and tunnels which have been built since 1446 to regulate the waters of Tezcuco and its three tributary lakes. Nevertheless, there have been certain periods when nature has triumphed over human endeavor and the waters have returned to the level which they would naturally occupy if man had never interfered. A comparison of the chief epochs of this sort seems to afford some ground for the belief that the climate of Mexico has passed through fluctuations like those of Asia on the one hand, and of more northern regions in America, such as California and New Mexico, on the other hand.

The great authority on early Mexico is Humboldt, whose "Essai Politique sur le Royaume de la Nouvelle-Espagne" was published in 1811 as the third part of the "Voyage de Humboldt et Bonpland." Later and less authoritative writers, such as Prescott and Romero, follow him closely, adding little that is new. Humboldt specifically states his belief that the climate of Mexico in his day was more arid than it was at the time of the founding of the capital about 1325 A. D. He attributes the change in part to undefined meteorological causes whereby evaporation has exceeded precipitation, and in part to the reckless destruction of forests by the Spaniards. He is sure that the level of Lake Tezcuco has fallen, through natural causes as well as through the works of man, and cites this fact as the chief evidence of a change of climate.

According to tradition, the Aztec founders of Mexico, like most of the world's great races, came from the north. After a century of adventurous wanderings, enlivened by the vicissitudes of war, conquest and slavery, they appear to have reached the shores of Lake Tezcuco about 1325 A. D. Hoping for peace and safety, they located themselves on some small islets several miles from the shore. There they laid the foundations of the present proud City of Mexico by sinking piles into the marshy shallows and erecting upon them light huts of reeds and rushes above the reach of the water. During the succeeding century, according to Humboldt's lucid account, the city grew and prospered and its rule spread over the neighboring regions. It was still an island city with houses on piles, with canals instead of streets in many cases, and with canoes in place of beasts of burden. Sometimes it suffered when the lake rose more than usual, which was presumably the reason for building the first known dike in the year 1446 A. D. Possibly, however, the dike happened to be built then merely because of an advance in the art of engineering; or perhaps it was because the increasing number of buildings in the city caused the land to settle, as it has done in recent years, when the erection of the new National Theater, for instance, has caused a local subsidence of four or five feet which is evident to the most casual observer by reason of the warping of the pavements of the streets. It seems probable, however, that the building of the dike may have had something to do with climate rather than with the other causes, for the water did not remain at a high level all the time thereafter, but at times, as happened near the end of the fifteenth century, fell so low that the city suffered much distress because canoes laden with supplies of food could not come in as formerly from the surrounding country. When Cortez came to Mexico in 1519 the capital was still a western Venice. He describes it as located on an island two leagues from the mainland. In order to besiege it effectively he was obliged to build brigantines, and in these he was able to sail completely around the city, except for a small distance on the southwest side toward Chapultepec, where the water was too shallow. The small boats engaged in ordinary traffic sailed everywhere, however, not only on Tezcuco, but on the other lakes and on the connecting rivers.

Two or three generations after the Spanish conquest the condition of the City of Mexico had changed. It had ceased to be an island, the canals had become dry; and wheeled vehicles had taken the place of canoes. This result was due in part to the construction of additional dikes, but nature apparently had been the main agent in the matter. Such seems to have been the opinion of Torquemada, a monk who lived in Mexico from the middle of the sixteenth century to the beginning of the seventeenth. He says, according to Prescott (page 33), that:

> As God permitted the waters which had once covered the whole earth to subside, after mankind had been nearly exterminated for their iniquities, so He allowed the waters of the Mexican lake to subside in token of good will and reconciliation after the idolatrous races of the land had been destroyed by the Spaniards.

About the time of Torquemada's death there occurred one of the periods of high water which, at that epoch, still periodically reduced the city to a partially inundated condition. To prevent such occurrences in the future a tunnel was built to carry off the surplus water of the Cuautitlan River. It might be supposed that, after the construction of the tunnel, the lake would never return to its natural condition. In 1629, however, during a season of uncommonly large floods the tunnel was blocked completely. The City of Mexico was flooded for a time and was in great straits during a period of extraordinarily rainy years lasting till 1634. Thereafter it became dry once more, although neither the tunnel nor the old dikes were in a condition to prevent the rise of the water. Again, from 1675 to about 1755, the tunnel was closed completely, being filled with earth for an unknown distance. At the same time also the dikes were in poor repair, breaking whenever the water rose higher than usual. Nevertheless, the city continued to stand on dry land. Sometimes, to be sure, a year of exceptional rains caused the water to rise sufficiently to flow into some of the streets, but not enough to do any serious damage.

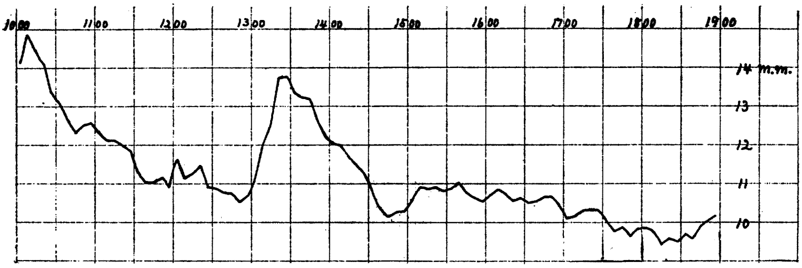

FIG. 1—Uncorrected curve of growth of the *Sequoia Gigantea* in California, based on 785 measurements. In the final curve, to which the requisite mathematical corrections have been applied, the left-hand portions will not rise quite so high as in the uncorrected curve here presented. The final corrected curve will be published in a volume entitled "The Climatic Factor" to be issued shortly by the Carnegie Institution of Washington.

Let us sum up the matter and at the same time compare the changes in Mexico with those indicated by the curves of growth of the *Sequoia Gigantea* in California and the yellow pine in New Mexico, as shown in Figures 1 and 2. It appears that about 1325 the level of the lake was high. For the next hundred years or more we do not yet know what occurred, but about 1446 there was a special reason for beginning to build dikes. This may possibly mean that the water had fallen from its position in 1325, and now rose again, a condition opposite to that of California. A little later, toward the end of the fifteenth century the water stood much lower than formerly, but rose again so that in 1520 the city was completely surrounded. This fluctuation, unlike its predecessor, appears on the whole to agree with the climatic tendencies of the same period in California as indicated by the curve of the Big Trees (Fig. 1). None of the other trees for which data are available furnish climatic curves of any accuracy going back as far as 1300, and neither this curve nor any other indicates the state of affairs in a region at all resembling southern Mexico climatically. Hence we make use of the curve of the sequoias merely as a suggestion of the method to be employed in future work. Mexico City in latitude 19° N. and the Sierra Nevadas 1,600 miles away in latitude 37° are so far apart and the difference between the equatorial summer rains of the southern region and the sub-tropical winter rains of the northern is so great that any marked agreement between the two is not to be expected. Nevertheless the high stand of the water of Tezcuco in the first half of the fourteenth century and its low stand toward the end of the fifteenth century agree distinctly with the fluctuations in the growth of the trees. From 1600 A. D. onward we are able to compare the changes in the city of Mexico with those in the state of New Mexico, a region which is not only not quite so remote as California, but which also receives part of its moisture from summer rains of the same type as those prevalent in southern Mexico. The New Mexican changes are indicated in Figure 2, the curve of growth of the yellow pine. About 1600 A. D., near the time of Torquemada's death, the country around Mexico City was comparatively dry, but a little later the lake rose, reaching an especially high level from 1629 to 1634. In New Mexico much the same thing took place, except that the moist period seems to have culminated somewhat later. At a still more recent period, from about 1675 to 1755, relatively dry conditions prevailed, both in the City of Mexico and in New Mexico. Since that time the increasing number of canals makes it impossible to judge of the climate from fluctuations of the lakes, but the data for the preceding years are at least enough to prove suggestive. The essential point of the whole matter is that the evidence so far as it goes appears to indicate that the enclosed lakes of Mexico have been subject to rather pronounced fluctuations lasting for many years and agreeing in a general way with those of other parts of the world, either farther to the north in America or in the distant regions of the eastern hemisphere. On the whole, the climate from 300 to 600 years ago seems to have been moister than that of to-day, although certain periods such as the end of the fifteenth century may have been dry.

The evidence just presented is in itself too slight to justify us in accepting any conclusion derived from it alone. Nor is that which follows any more conclusive. At present, however, our purpose is merely to test a theory whose basis has been elaborated in previous publications. The most rigid test is to see if the theory can stand when applied to places and conditions far removed from those under which it was framed. Thus we select as many tests as possible in Mexico, but must recognize that in themselves they are not sufficient to form the basis of a broad theory. If the lakes of Mexico have fluctuated in size, the deposits of the surrounding plains ought to show corresponding variations. Fortunately, Mr. Manuel Gamio, under the direction of Professor Franz Boas, has recently been engaged in archæological excavations on behalf of the International School of American Archæology and Ethnology, and has done some work which is significant for our present purpose. The hamlet of San Miguel Amantala near the village of Azcapotzalco lies on the edge of the lacustrine plain of the City of Mexico not far from the base

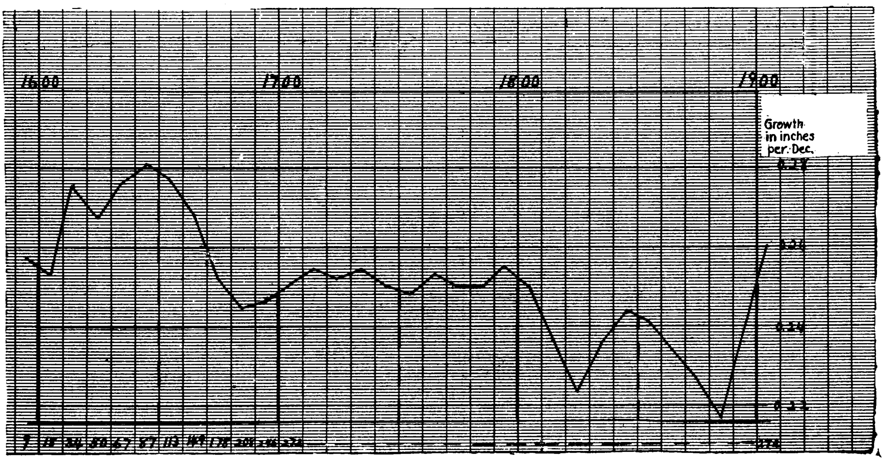

FIG. 2—Curve of growth of the yellow pine in New Mexico, deduced from measurements made by the U. S. Forest Service. (Numerals 19, 18, 34, etc., indicate number of trees used.) "Dec." in upper right-hand corner stands for "decade."

of the hills on the west. This portion of the plain is dotted with little mounds which mark the sites of villages or small groups of houses built by the Aztecs and full of the typical pottery, images and other relics of that people. Elsewhere the plain is strewn with the scattered fragments of another and older type of civilization which is known as that of San Juan Teotihuacan from the great pyramids of that name on the eastern border of the basin of Mexico. The San Juan relics never occur in mounds of the Aztec type except for a few stray bits which have been carried in by accident. This indicates that the two are of distinctly different dates, as indeed we know from other evidence. Some of the mounds of Aztec age appear to be merely accumulations of earth from the adobe roofs and walls of the ancient dwellings but others appear to have been built of set purpose. This suggests that for some reason the earlier people built their houses directly upon the plain, while the later Aztecs raised theirs upon mounds. To Professor Boas this fact seems to indicate merely that before coming to the Mexican plateau the Aztecs had probably acquired the habit of building elevated structures and that this persisted throughout their history. Possibly, however, the elevation was an advantage for purposes of defence; or perhaps, at the coming of the Aztecs, the level of the lakes was so high that in times of unusual rain the villages were occasionally in danger of inundation, although during the days of their predecessors, the San Juan people, the plain may have been so dry that no such danger existed.

In one of the sites marked by San Juan pottery Professor Boas has made an excavation in which he finds the following section from the top downward:

(A) 1 or 2 feet of fine, dark surface soil full of bits of San Juan pottery.

(B) 6 inches to two feet of "tepetate", or "caliche" as it is called farther north, in layers from one inch to one foot in thickness. It is mixed with bits of San Juan pottery and is interstratified with layers of well-rounded gravel containing pebbles up to two or three inches in diameter. The "tepetate" is a white calcareous deposit which is frequently formed in dry regions where a large amount of water evaporates. It is usually considered characteristic of rather arid conditions. Here at Azcapotzalco it is frequently faulted a few inches as if the ground had sunken a little.

(C) 4 or 5 feet of "culture layers" full of San Juan pottery intermingled with ashes, fireplaces, and the foundations of ancient houses.

(D) 5 or 6 feet of fine sand, often in pockets or in slightly cross-bedded bands. This is intermixed with finer sandy materials and a certain amount of clay like that which forms the bulk of the overlying culture layers. Fragments of pottery of the same San Juan type, together with bones and angular stones as much as a foot in diameter, indicate that men lived here when the layers were being laid down, although there are no foundations.

(E) 11 or 12 feet of gravel and sand growing coarser downward, and at the base containing cobblestones a foot in diameter. The pebbles are mostly well-rounded as if they had been carried far in running water, although a few angular pieces are found, especially in the more clayey portions of the sand. San Juan pottery occupies the upper five or six feet, but only in small quantities. The fragments are often angular, showing that they have not been carried far in running water. The lower five or six feet contain quite a different type of pottery, belonging apparently to the type which Professor Boas has called the Mountain culture. It is much more archaic than the San Juan or Aztec types, and it is certainly older, since it lies lower. Whether it persisted until the time of the later cultures we cannot tell. Professor Boas says that as yet it has nowhere been found on the surface of the plain, although it is common in small areas scattered among the surrounding mountains. Hence its name. The pieces found by Professor Boas in his excavations were all well rounded, showing that they had been carried some distance by running water, or in other words, that they had been brought in from the mountains.

At a short distance from the main excavation Professor Boas found that the gravels of this formation die out. Minor excavations in several places led him to conclude that the main gravel just described indicates the location of a river bed less than a hundred meters wide and extending in a north and south direction. Outside the river bed, but at the same level, the coarseness of the decomposed tufaceous matter increases a little, and the material is more sandy than above or below, indicating sorting by moving water. In the sandy material the archaic pottery of the Mountain culture is found in large amounts. It is not stream-worn or rounded, and the paints with which it is decorated are still fresh. Clearly it has not been carried far, which indicates that the plain near the old river, or torrent, must have been inhabited. Whether this pottery is of the same age as the worn fragments in the river bed is uncertain. It may be younger, for Professor Boas thinks that there was a gradual transition from the Mountain culture to that of Teotihuacan.

(F) At the base of the gravels a dark, compact clay is found to a depth of about 7 feet. It contains almost no sand, but is full of plant remains, and of hydrated iron which stains it yellow. The formation looks like the deposit of a swamp or of the edge of a lake. It is sharply separated from the overlying gravel in a way to suggest a drying up of the swamp and a sudden bringing in of materials by streams which had formerly had their mouths nearer the mountains. So far as the clays have yet been studied they contain no pottery or other evidences of human occupation.

(G) Finally, the lowest formation thus far penetrated is a light-colored sand which Professor Boas thinks to be lacustrine.

The single section here given is of course inconclusive. The transition from one type of deposits to another may have arisen from a change in the course of streams by reason of an earthquake or volcanic eruption, or it may have been due to a tilting of that particular portion of the earth's crust. Nevertheless, it is interesting to see how closely it agrees with what would be expected if the climate of Mexico has varied in harmony with what seems to have been the case in other parts of the world. The apparently lacustrine deposits of G, and the swampy deposits of F, to begin with the oldest formation, suggest conditions of decided moisture with such an expansion of the lakes that the floor of the basin was uninhabitable and the people were forced to live in the surrounding hills where they developed their Mountain culture. The succeeding gravels suggest a change to drier conditions whereby the shore of the swamp or lake retreated and streams began to encroach upon the old water-covered bed. At the same time the death of vegetation upon the mountain slopes because of the aridity would permit the floods to wash down large amounts of coarse gravel, with which would be mingled rounded, waterworn bits of pottery from the mountain villages, as appears in the lower part of formation E. During this dry time, if such it really were, the people of the Mountain type apparently came down to the plain as is indicated by the unworn pottery at the base of formation E in the portions of that formation outside the river channel. A little later, the San Juan culture, perhaps that of an invader, makes its appearance close to the base of the mountains at first, or on the very edge of the plain as indicated by the fact that it is present in the gravels, but is free from marks of wear by running water. By the time deposit D began to be laid down the San Juan people were living not far from the site of the excavations. When C was being formed conditions were very much as now. B, on the contrary, with its layers of "tepetate" and gravel suggests a return toward aridity, while A brings us back to the present conditions. If the elevation of the Aztec mounds, built since the deposition of A, really has anything to do with the danger of flooding, it may indicate a slightly moister time such as that of which the traditions give a suggestion in the fourteenth century, while now in the nineteenth and twentieth centuries we are back once more in dry times. The whole importance of the line of reasoning here followed is quite independent of the fact that the specific phenomena described above are subject to other possible explanations. It lies rather in the fact that the explanation here offered harmonizes with a vast number of other facts both in Mexico and elsewhere and genuinely explains them, while the other explanations take little account of anything outside of the narrow range of the phenomena immediately under consideration.

One of the important methods of testing the theory here suggested is the occurrence or non-occurrence of the type of terraces which seem to be of climatic origin. I have discussed this matter at length in "Explorations in Turkestan" so far as it applies to Asia, and shall discuss it further in respect to America in a forthcoming report to be published by the Carnegie Institution. Here it must suffice to say that in both Asia and America the drier, more rugged mountains of non-glaciated sub-tropical regions are full of alluvial terraces composed of gravel and silt, and ranging in height from ephemeral ones five feet in height to enduring ones a thousand feet high. Generally the terraces are more than one in number and in practically all cases where they are well developed there are four or five. They are of such a nature, and are so located in interlocking valleys on all sides of the mountains that they can scarcely be due to movements of the earth's crust, unless we make the impossible assumption that the crust moved in such a way as to steepen all valleys at one time and flatten them at another no matter what their direction. The only other process yet suggested which adequately explains the terraces is climatic variations causing the rate of erosion and weathering as well as the volume and velocity of the streams to change.

Terraces of the kind here considered seem not to have been described by the geologists of Mexico, but when I inquired about them I was told that they are abundant in the states of Chihuahua, Durango and elsewhere in the northwest. I had previously seen them in large numbers and in a highly developed condition in Sonora, the extreme northwestern portion of Mexico, and also along the portion of the railway line from Laredo to the City of Mexico in the vicinity of Monterey in the northeast. Through the courtesy of Dr. José G. Aguilera, Director of the Geological Institute of Mexico, one of his assistants, Mr. Ygnacio S. Bonillas, was permitted to spend some days with me in studying the region around the City of Mexico. Thanks to Mr. Bonillas's thorough knowledge of the local geology I was able in a short time to see things which it would have taken me weeks to find alone. He took me out to the northwest of the city where the volcanic hills are deeply seamed with rugged ravines descending from high mountains. There in four valleys we found terraces of the kind under discussion. The presence of revolutionists within three or four miles of the places where we were at work prevented us from examining others or from following any of the four up into the mountains where the maximum development is to be expected. Nevertheless, the places shown by Mr. Bonillas were sufficient to suggest that valleys which are of sufficient size and which come from mountains of sufficient height and youth, contain alluvial terraces of the type which elsewhere seems to be climatic. In various places the cross section of the valleys is like that shown in Figure 3. The calcareous "caliche" or "tepetate" (2) on the top of the main volcanic deposits (1) suggests a long dry epoch. The rapid cutting to form the gorge A, indicates either a pronounced uplift, or a period of comparative moisture during which the streams were able to erode rapidly, either because of their large volume or because they were lightly loaded with detritus by reason of the covering of the slopes with vegetation. The alluvial filling 3, indicates either a tilting of the earth's crust back toward its original position, or a period of aridity during which the streams diminished in size and gained a heavier load because of the death of vegetation. The same process of cutting and filling was repeated at least twice, and possibly several times, although the evidence is now concealed or has been worn away. Similar phenomena on a much larger scale occur farther south, especially in the valley of the Papaloapan River nearly 200 miles southwest of Mexico City between Pueblo and Oaxaca. Here the terraces reach a height of at least 200 or 300 feet, and are developed to the number of four over long distances. They are apparently of the same type as those in regions hundreds and thousands of miles away, and appear to be due to a common cause which can scarcely be anything but climatic pulsations. The constant occurrence of such terraces from Utah on the north through Mexico to the far south of that country, and their high development even at the southern limit to which they have yet been traced seem to be strong indications that whatever climatic changes have taken place in the United States have also taken place in Mexico, although the phases of change may have differed in the two places.

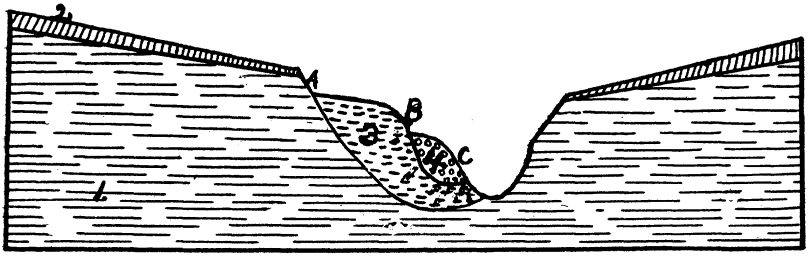

FIG. 3—Cross section of alluvial terraces in a typical valley among the volcanic hills near the City of Mexico. 1 = volcanic tuff. 2 = "caliche." 3 and 4 = first and second alluvial deposits of gravel and sand. A, B, and C = successive gorges.

(*To be concluded.*)